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Thermal perception of teenagers in a cool outdoor environment: A case study

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Subjective thermal sensation of late teenagers was examined aiming to reveal potential discrepancies in its estimation compared to adults. Since teenagers have different clothing habits and preferences from adults, it is important to know whether the conclusions reached by studies on thermal sensation, usually involving adults, can be also applied to teenagers. A group of late teenagers was interviewed, based on a structured questionnaire, in an outdoor environment during two winter days and under an unexpected Saharan dust transport event during the second day, while meteorological measurements were obtained by the closest to the interview site weather station. Moreover, the performance of the bioclimatic index Cooling Power in simulating subjects' thermal sensation was evaluated. Although differences in clothing thermal insulation of late teenagers compared to that suggested by similar studies were recognized, generally the results of this study were in agreement with the findings of similar field surveys focusing on individual thermal sensation and with no evidence of effects of the dust transport event on thermal sensation. Cooling Power based on the Mediterranean thermal sensation scale predicted thermal sensation vote fairly well.

Keywords: perception**,** thermal sensation, questionnaire survey, thermal index, cooling power

1. Introduction

Outdoor thermal sensation and comfort are issues that attract the interest of scientific community for many years and various purposes. In recent years this interest has focused on health (Kovats and Hajat, 2008) and outdoor urban planning purposes (Chen and Ng, 2012), aiming to improve the quality of life in the cities. Moreover the interest about thermal perception was intensified by studies indicating the climate change and the increase in the number of extreme weather events such as heat waves or cold spells.

In that context, several studies have been conducted in different climatic zones, in order to investigate factors influencing or determining thermal sensation (Cheng et al., 2012; Krüger and Rossi, 2011; Pantavou et al., 2013) whereas others have been focused on its modeling and estimation (Monteiro and Alucci, 2008; Pantavou and Lykoudis, 2014). RUROS project (RUROS, 2014) was one of the first field surveys in the past decade quantifying comfort conditions outdoors that indicated the deviation of theoretically estimated from actual thermal sensation and highlighted the importance of psychological factors, such as preference, in the evaluation of thermal perception. Since then, other studies have been published also exploring thermal perception through field surveys (Thorsson et al., 2004; 2007) while in the most of them, the majority of the interviewees were adults (Oliveira and Andrade, 2007; Pantavou et al., 2013).

However it has been found that there are thermoregulatory differences related with age (Frank et al., 2000) while according to the Environmental Protection Agency of US (EPA, 2014), children may be more vulnerable to environmental factors than adults. Moreover, considering the fact that standards of thermal sensation models as well as that the majority of biometeorological indices simulating thermal sensation are referred to a man aged 35 years old whereas they are applied for children and teenagers, it is evident that more research should be done focusing on outdoor children's and teenagers' thermal sensation.

This research inquires into outdoor thermal perception of late-teenagers trying to detect potential variations in thermal perception between adults and teenagers that could be attributed to the different metabolic rate, clothing type or preference of younger people. Also the performance of a selected biometeorological index in simulating thermal sensation was evaluated.

2. Materials and methods

Kalamata is a city in southwestern Peloponnese, in southern Greece. It is an important urban, economic and commercial center, located at the edge of mount Taygetos, in the heart of Messinian Bay. It has a temperate Mediterranean climate; during February, the climate of Kalamata is mild and wet, with an average, maximum and minimum air temperature of 10.6 °C, 15.5 °C and 5.6 °C respectively, average relative humidity 71.7% while it receives 99 mm of precipitation (HNMS, 2014). February is the most representative month of winter in Greece. The difference between the mean climatic values (1961–1990) of February and the corresponding values during the winter period (December-January-February) are smaller compared to the December or January ones, in the majority of the meteorological parameters (NOA, 2014). Moreover people are adapted in winter thermal conditions.

Table 1. Questionnaire used in the study.

Outdoor Thermal Comfort Questionnaire Note: This questionnaire is entirely voluntary, if you do not wish to complete it, or any part of it, you are under no obligation to do so			
1. Date:……	**2. Time:**……..	**3. Gender:** □ Male □ Female	
4. Clothing: *Underline all the items closest to what you are wearing at this moment*: – *Tshirt / Shirt* (thin/normal/thick) (Short/ Long/No sleeved), *Sweater* (thin/normal/thick) – *Shorts, Pants* (thin/normal/thick), *Skirt* (thin/thick), *Dress* (thin/thick) – *Jacket* (thin/thick), *Down Jacket*, *Coat* – *Shoes* (thin/thick soled), *Boots* – *Socks* (long / short) – *Sunglasses*, *scarf*			
Are your clothes mainly** LIGTH **or** DARK **in colour?			
5. Dressed as you are at the moment, please tick the scale to indicate how you currently feel □ cold □ cool □ slightly cool □ neutral □ slightly warm □ warm □ hot			
6. How would you prefer to feel at this moment? □ cooler □ no change □ warmer			
7. How do you think that your thermal condition would be improved at this moment?			
in relation to air temperature	□ higher	□ no change	□ lower
in relation to humidity	□ higher	□ no change	□ lower
in relation to wind speed	□ higher	□ no change	□ lower
in relation to irradiance	□ higher	□ no change	□ lower

A group of 22 young people aged 17–18 years old were interviewed twice, once each day, using a structured questionnaire. The interviews were conducted at the outdoor area of the Environmental Education Center of Kalamata where the group of people was visiting. The questionnaire (Tab. 1) included the main question of thermal sensation vote (TSV) (Tab. 1, question 5) in which the interviewees were requested to assess their thermal sensation based on a 7-point scale ranging between –3 and +3 (–3, cold; –2, cool; –1, slightly cool; 0, neutral; +1, slightly warm; +2, warm; +3, hot) (ISO 10551, 1995). Moreover, the questionnaire included questions related to clothing type (Tab. 1, question 4), in order to calculate respondents' thermal resistance from the skin to the outer surface of the clothed body named thermal insulation (I_{cl}, in clo) (ISO 9920, 1993). The most common unit of thermal insulation is clo. One clo is defined as the thermal insulation necessary to maintain the thermal balance of a sitting subject in a room with the following ambient parameters: air velocity equal to 0.1 m s^{-1}, air and wall temperature at 21 °C and relative humidity less than 50% (Fanger, 1970). Furthermore, the respondents were asked to indicate their preference (Tab. 1, question 5) with respect to overall sensation (Tab. 1, question 6), ambient air temperature, humidity, wind and irradiation (Tab. 1, question 7).

The interviews were conducted in two consecutive days, 19^{th} and 20^{th} of February, in midday (12:30 to 13:10) and afternoon (17:30 to 18:00) respectively. On the days of the experiment, the weather was relative warm for the season and wet with an incidence of Saharan dust episode (NOA, 2010). The levels of air pollution by particulate matter (PM10) recorded in several stations of Ministry of Environment Energy and Climate Change (MEECC, 2014) throughout the country were significantly high especially on the second day of the interviews (20^{th} February) (Tab. 2). The nearest stations to Kalamata, two air pollution stations in Patras, recorded average daily PM10 concentration 163 $\mu g\, m^{-3}$ and 180 $\mu g\, m^{-3}$ on the first and 464 $\mu g\, m^{-3}$ and 497 $\mu g\, m^{-3}$ on the second day of the interviews. The pictures of the satellite MODIS and NOAA (AERONET, 2014; WDC, 2014), not shown here, also confirm the Saharan dust transport over Greece. This phenomenon occurs a few times a year in Greece, mainly during the transitional months of spring, but it is extremely rare during February. The meteorological observation data of Kalamata station (LGKL) reported a dust event from 6:20 UTC until 21:50 UTC on 20^{th} February.

Table 2. Average daily PM concentrations recorded during four days of February (Feb) in several stations of Ministry of Environment in Greece.

Latitude	Longitude	City – Station	Parameter	Concentration ($\mu g\, m^{-3}$)			
(deg)	(deg)			18-Feb	19-Feb	20-Feb	21-Feb
40.64	22.96	Thessaloniki – Ag. Sofia	PM10	59	60	188	37
40.58	22.96	Thessaloniki – Kalamaria	PM10	39	36	206	45
39.66	22.45	Larissa	PM10	27	19	152	10
39.61	20.85	Ioannina	PM10	62	52	334	20
39.61	20.85	Ioannina	PM2.5	22	16	97	13
39.36	22.95	Volos	PM10	52	42	475	41
38.31	23.64	Oinofita	PM10	72	105	342	235
38.25	21.73	Patra – 1	PM10	222	163	464	81
38.24	21.73	Patra – 2	PM10	237	180	497	94
38.04	23.46	Lykovrisi	PM10	119	143	388	125
38.04	23.46	Lykovrisi	PM2.5	34	42	111	38
38.01	23.47	Marousi	PM10	90	106	260	108
37.90	23.88	Koropi	PM10	125	132	332	91
37.59	23.43	Aristotelous	PM10	150	177	421	127

Table 3. Classification of Cooling Power (CP) and the calibrated thresholds for the Mediterranean climate (Pantavou, 2014).

Thermal Sensation Vote	Classification	CP (W m^{-2})	CP_{MED} (W m^{-2})
–3	Cold discomfort	≥ 1050	> 725.3
–2	Cold subcomfort	700 – 1049	725.2 – 587.7
–1			587.6 – 381.4
0	Comfort	350 – 699	381.3 – 193.9
1	Hot subcomfort	175 – 349	193.8 – 53.1
2			53.2 – –99.1
3	Hot discomfort	0 – 174 ≤ 0	< –99.2

The ambient temperature varied between 8 °C and 19 °C and relative humidity ranged between 60% and 94%. The meteorological data used in the study, were obtained from the weather station of Kalamata's airport (code LGKL, 37° 4' 6" N, 22° 1' 32" E) (UW, 2010). The station provides data of air temperature (T_{air}, °C), dew-point temperature (T_d, °C), relative humidity (RH, %), atmospheric pressure (hPa), wind speed (WS, m s^{-1}) and wind direction, visibility and precipitation while data are updated on hourly basis.

Trying to investigate young people's individual thermal sensation in a Mediterranean climate, the analysis was focused on respondents' *TSV* and their relation with the examined environmental, personal (clothing type) and psychological factors (preference). Chi-square test was used for the analysis of categorical variables and analysis of variance (one-way ANOVA) was applied between categorical and continuous variables. Ordinal regression was used in order to investigate the factors that were independently associated with *TSV*. All results presented are statistically significant on a level of equal or smaller than 0.05.

Furthermore, the bioclimatic index Cooling Power (CP, in W m^{-2}) (Siple and Passel, 1945) was estimated in order to examine theoretically the subjective thermal sensation as well as to evaluate *CP* performance in the case of a Mediterranean climate. The choice of the index was based on the data available and its applicability to Mediterranean climate (Pantavou, 2014). *CP* can be estimated by the equation:

$$CP = 1.163\,(10.45 + 10\,WS^{0.5} - WS)\,(33 - T_{air}) \quad (1)$$

where WS is wind speed in m s^{-1} and T_{air} is air temperature in °C.

CP predictions were tested using Mediterranean assessment scale as well (Pantavou, 2014) (Tab. 3). Since thermal sensation and thermal comfort scales are used by the respondents in the same manner (Nicol, 2008), *TSV* assessment scale was adjusted to *CP* scale based on the verbal description of thermal sensation.

3. Results

From a meteorological point of view, the Saharan dust transport event was characterized by uniform – without great variations – dry bulb and dew point temperatures (Fig. 1) both on the surface and with height. On 20th February, the ambient temperature range was reduced to 6 °C from 12 °C and 11 °C that were recorded during the previous two days (18th and 19th February) while on the next day (21st February) the temperature range rose again to 11 °C (Fig. 1a). Similar to T_{air}, T_d range (4 °C) was lower on 20th February compared to the respective recorded range (8 °C) during the two previous days and the next day (18th, 19th and 21st). Figure 1b demonstrates the layer of dust transferred by Sahara at the level of 850 and 650 hPa, where an isotherm layer is observed, indicating an air mass with uniform features. The daily range of RH was decreased from about 30% on 18th, 19th and 21st to 20% on 20th February (Fig. 2a). Wind speed was generally low (Fig. 2b) with an increasing daily average over the days of the experiment. The daily average of wind speed was estimated 0.9 m s^{-1} on 18th, 1.1 m s^{-1} on 19th, 1.4 m s^{-1} on 20th and 2.6 m s^{-1} on 21st of February. The daily variation of atmospheric pressure (Fig. 2c) was about 1012 hPa on 18th of February, while two days after (on 20th February) reached its minimum value (1005 hPa).

During the interviews, the air temperature was ranged between 14 °C and 17 °C, the relative humidity was measured between 82% and 88% and the wind speed was low reaching the maximum value of 2 m s^{-1}. The weather was generally cloudy.

The number of the completed questionnaires was 44. About 54.5% of the interviewees were males, 65.9% were dressed with dark color clothes, 52.3% the last half hour were mainly standing while the rest were mainly seating indicating overall a low activity. The respondents can be considered as acclimatized since they were at the interview site for over an hour.

Although the variance of air temperature during the interviews was low, the clothing thermal insulation (I_{cl}) was varied among the interviewees between 0.52 clo and 1.03 clo. The average I_{cl} value (0.80) was lower than the typical indoor winter clothing combination (1.0 clo) (ISO 7730, 1994) while I_{cl} showed a moderate correlation (0.52, $p < 0.01$) with the I_{cl} derived both from the UTCI-clothing model or the model presented in the study of Pantavou et al. (2013) indicating that younger people differ in terms of ordinary clothing insulation values from that suggested by ISO 7730.

The *TSV*s ranged between –3 and +2 (Fig. 3a) indicating the variability of subjective thermal perception. About 36.4% of the interviewees indicated thermal sensation slightly cold (–1) and 40.9% indicated neutral (0). The mean T_{air} in which the respondents felt 'neutral' was 15.3 ± 1.3 °C in accordance to the study of Pantavou et al. (2013) where neutral temperature was estimated at 15.8 ± 2.8 °C. Considering preference (Fig. 3b), it was revealed that although 77.3% voted 'slightly cool' or 'neutral' thermal sensation (–1, 0), about 63.6% preferred an environment with different air temperature. The 29.5% of the interviewees preferred lower air temperature as well as 38.6% preferred higher wind speed, depicting the effect of expectation, since the experiment was carried out in winter, while 34.1% preferred higher air temperature depicting the preference of people in warmer thermal conditions and in good weather. The last was reinforced by the preference vote in relation to irradiance. Some of 56.8% of the respondents preferred higher solar radiation while 40.9% indicated 'no change'. The majority

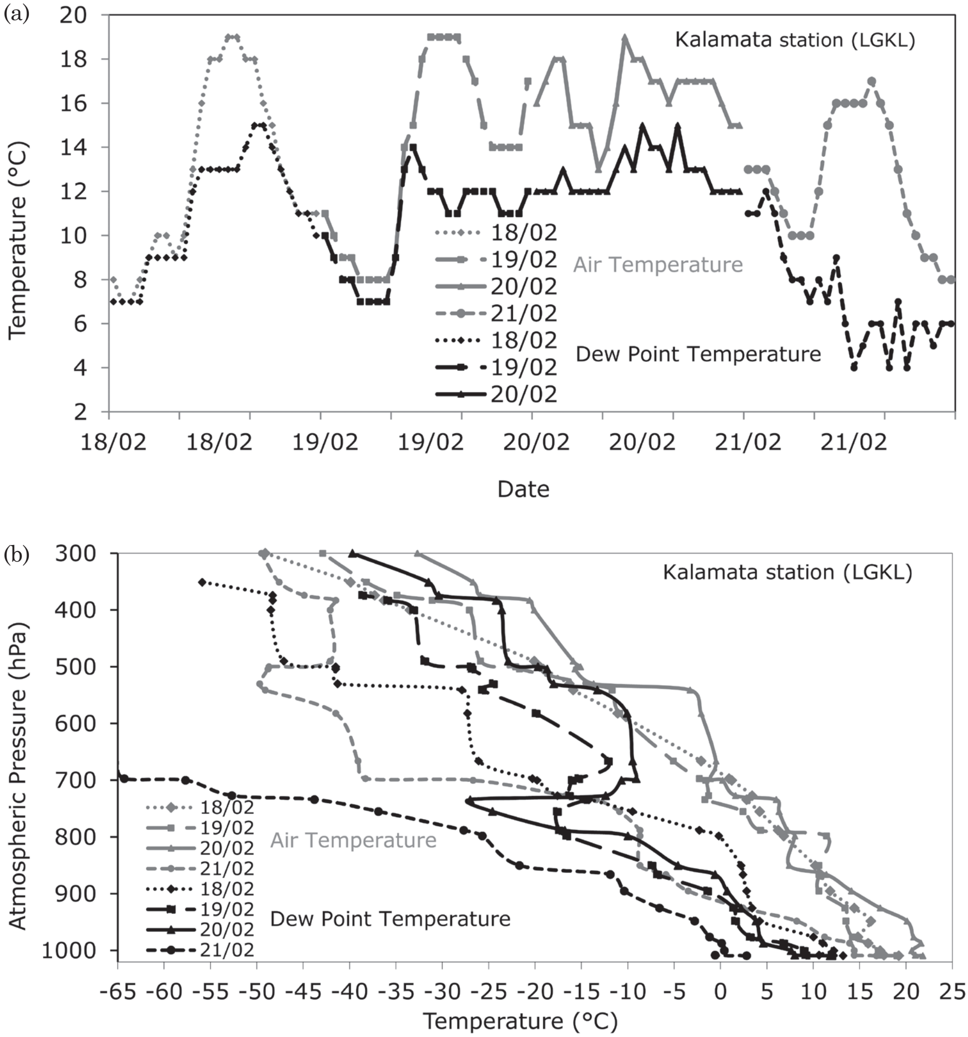

Figure 1. Variation of air temperature and dew point temperature on surface (*a*) and with height (*b*).

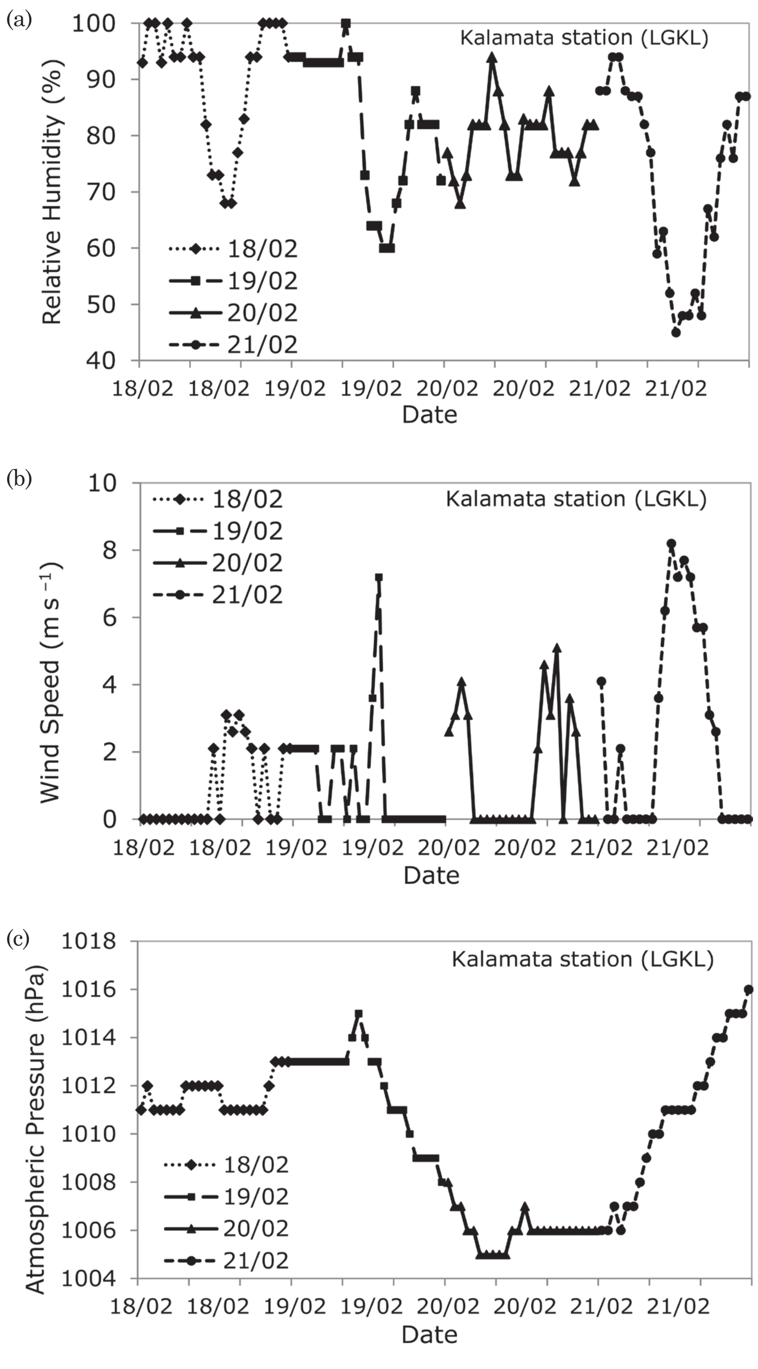

Figure 2. Daily variation of relative humidity (*a*), wind speed (*b*) and atmospheric pressure (*c*).

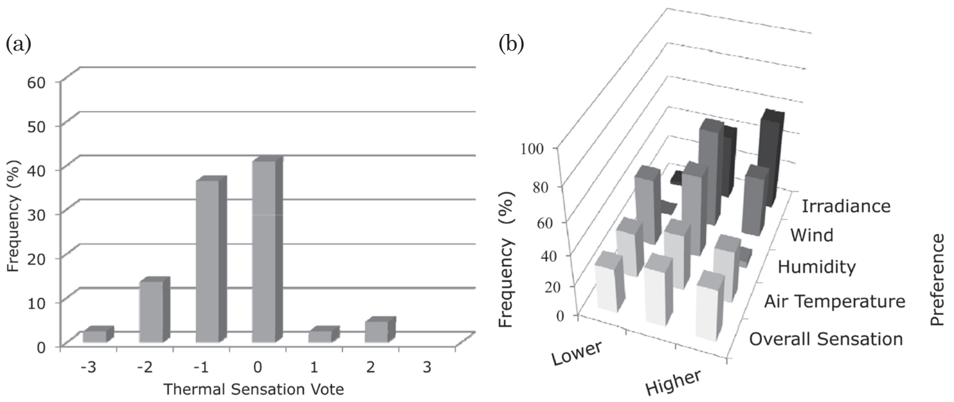

Figure 3. Frequencies of thermal sensation votes (*a*) and preference votes (*b*).

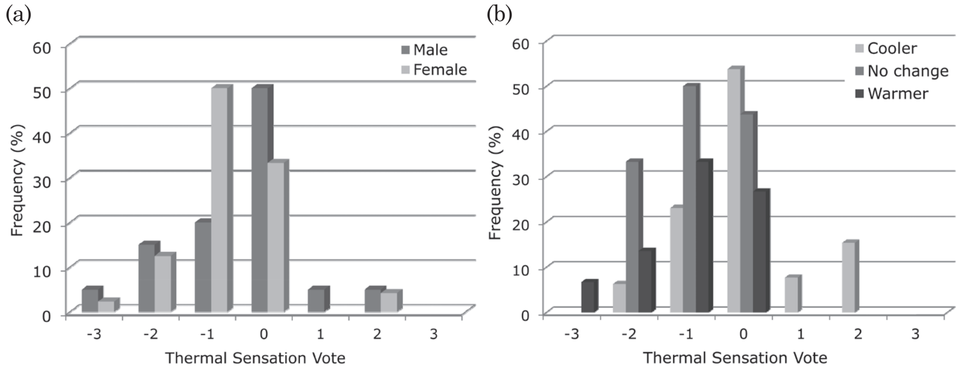

Figure 4. Frequencies of thermal sensation votes by gender (*a*) and preference of overall thermal sensation (*b*).

of the interviewees (52.3%) reported that they wished 'no change' in relation to *RH* while 43.2% indicated that they would prefer lower values of *RH* indicating that in extreme conditions of *RH* the reaction of people is the expected one. The observed low rate in preference related to higher humidity (Fig. 3b), could be attributed to the fact that people's perception in relation to *RH* is doubtful (Nikolopolou and Lykoudis, 2006; Oliveira and Andrade, 2007; Pantavou et al., 2013). The wind speed during the interviews was kept low, while the majority of the interviewees preferred 'no change' in relation to wind (61.4%), in accordance to the conclusion of Pantavou et al. (2013) that high wind speeds were unfavorable. The rest of the respondents (38.6%) preferred a higher wind velocity probably due to expectation.

Cross-tabulation between gender and *TSV* (Fig. 4a) demonstrated higher percentage of thermal sensation votes between –3 and –1 in females (64.8%) than

(a) Thermal Sensation Vote (%)

Cooling Power (*CP*)	-3	-2 -1	0	1 2	3
-3	**0,0**	0,0	0,0	0,0	0,0
-2 -1	0,0	**0,0**	0,0	0,0	0,0
0	0,0	50,0	**40,0**	10,0	0,0
1 2	2,9	50,0	41,2	**5,9**	0,0
3	0,0	0,0	0,0	0,0	**0,0**

(b) Thermal Sensation Vote (%)

Cooling Power (CP_{MED})	-3	-2 -1	0	1 2	3
-3	**0,0**	0,0	0,0	0,0	0,0
-2 -1	0,0	**50,0**	40,0	10,0	0,0
0	2,9	50,0	**41,2**	5,9	0,0
1 2	0,0	0,0	0,0	**0,0**	0,0
3	0,0	0,0	0,0	0,0	**0,0**

0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100

Figure 5. Cross-tabulation of predicted thermal sensation votes by (*a*) the bioclimatic index Cooling Power and (*b*) the bioclimatic index Cooling Power based on the Mediterranean assessment scale (each row adds to 100%, bold values indicate correct predictions, gradient shading relates to the percentage number and darkens per 10%).

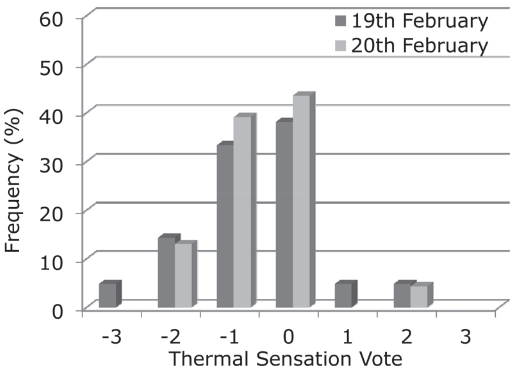

Figure 6. Frequencies of thermal sensation votes by day.

in males (40.0%), indicating a higher sensitivity to cold in females in accordance to the result of Pantavou et al. (2013) that women are more vulnerable to thermal conditions than men. In fact 50% of females' *TSV*s indicated slightly cool thermal sensation whereas 50% of males indicated neutral.

Some of 83.3% of the respondents reported preference 'no change' with respect to overall thermal sensation (Fig. 4b) voting –2 and –1 thermal sensation while 83.2% reported 'cooler' voting –2, –1 and 0, demonstrating in general a preference to cooler thermal sensation, probably attributed to expectation. Similar results were obtained in the case of preference with respect to air temperature.

Ordinal regression revealed significant relationship only between *TSV* and overall thermal preference as well as between *TSV* and preference in relation to air temperature and irradiation, pointing the dependence of *TSV* on psychological factors such as preference. According to ordinal regression analysis the probability of voting higher *TSV* increases when overall preference of thermal sensation is 'cooler' (–1) in relation to 'warmer' (+1).

CP ranged between 206.6 W m^{-2} and 420.4 W m^{-2} suggesting 'neutral' or 'slightly warm – warm' thermal sensation (Fig. 5a), one class warmer than that indicated by the respondents. *CP* predictions were improved when the Mediterranean scale (Pantavou, 2014) was used (Fig. 5b). According to the Mediterranean scale *CP* simulations ranged between 'neutral' and 'slightly cold' – 'cold' while *TSV*s were predicted fairly well despite the relative small size of our sample.

Analysis per day revealed higher rates of votes in the extreme categories (–2, –3) of thermal sensation scale (Fig. 6) on the first compared to the second day of the interviews while higher rate of *TSV*s was observed on 20th February in the categories –1 and 0, likely due to the fact that air temperature measured higher during the interviews on the 2nd day. However *CP* indicated cooler thermal sensation on 20th than on 19th February possibly attributed to the higher wind speed recorded on the second day. Interestingly, on 20th February the average value of thermal insulation of clothing was also greater (0.87) compared with that on 19th (0.73) highlighting the effect of adaptation on thermal sensation as well as the significance of personal factors on the estimation of thermal sensation. There was no result that could be attributed or justified by the dust episode observed on the 2nd day of the interviews was revealed by the analysis of data.

4. Conclusion

The present study explores the subjective thermal sensation of late-teenagers aiming to enrich our knowledge of the outdoor comfort and thermal environment, since thermoregulation, metabolic production and personal characteristics such as clothing type or preference vary with age. Subjects were interviewed based on a structured questionnaire while meteorological measurements were obtained by the closest to the interview site station. Considering the small sample size and the relatively small number of questionnaire responses, the results of this study could be considered as only indicative of late-teenagers in a Mediterranean climate.

Younger people tend to dress lighter than adults, wearing clothes with lower thermal insulation than that suggested by similar studies or international standards. Although the interviews were conducted in the winter there was a very small percentage of thermal sensation votes in the class 'warm' highlighting the variability of subjective thermal perception. Generally the results of the present study are in agreement with the findings of similar field surveys focusing on adults' thermal sensation (Pantavou et al., 2013). Subjects' responses revealed the effect of expectation and preference on thermal sensation as well as their preference for warm thermal conditions. Females tended to be more vulnerable to the cold environment than males voting in a higher rate the extreme classes of the thermal sensation scale while windy conditions were unfavorable. No evidence of effect on thermal sensation was found by the increased particulate matter concentration.

The bioclimatic index Cooling Power based on the Mediterranean scale simulated thermal sensation vote fairly well despite the relative small data sample and the limited range of thermal sensation votes.

An extended survey that would include a larger sample size and variability of weather conditions would be beneficial and would improve further our understanding related to teenagers' perception of the thermal environment. Further research and additional data will be needed to clarify the effect of particulate matter pollution on thermal sensation.

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SAŽETAK

Toplinska percepcija tinejdžera u hladnom vanjskom okruženju: Analiza slučaja

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Ispitan je subjektivni toplinski osjet ugode starijih tinejdžera s ciljem da se otkrije njegovo moguće neslaganje s procjenom s osjetom ugode u odraslih. Kako se navike i sklonosti oblačenja tinejdžera razlikuju od onih u odraslih, važno je znati da li su zaključci dobiveni na temelju studija o toplinskom osjetu ugode, koji se uglavnom odnose na odrasle, primjenjivi i na tinejdžere. Grupa starijih tinejdžera anketirana je u vanjskom okruženju putem strukturiranog upitnika tijekom dva zimska dana, od kojih je drugi bio obilježen neočekivanim prodorom saharskog pijeska. Meteorološka mjerenja su dobivena s meteorološke postaje koja je bila najbliža mjestu anketiranja. Nadalje, ocijenjena je primjenjivost bioklimatskog indeksa ohlađivanja (*Cooling Power*) pri simuliranju toplinskog osjeta ugode ispitanika. Iako postoje razlike u toplinskoj izolaciji odjeće starijih tinejdžera u usporedbi s odjećom ispitanika u drugim studijama, rezultati ove studije općenito su u skladu s rezultatima sličnih studija koje se bave individualnim toplinskim osjetom. Nadalje, utjecaj transporta saharskog pijeska na toplinski osjet nije zabilježen. Indeks ohlađivanja koji se temelji na mediteranskoj skali toplinskog osjeta ugode prilično je dobro predvidio rezultate anketa o toplinskom osjetu ugode.

Ključne riječi: percepcija, toplinski osjet ugode, anketno ispitivanje, toplinski indeks, indeks ohlađivanja

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